SHASTA LAKE
WATER RESOURCES INVESTIGATION

APPENDIX D

Fish Survival and Habitat Analyses

U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region

TABLE OF CONTENTS

Items **Page**

CHAPTER I INTRODUCTION

METHODOLOGY I-1

CHAPTER II EFFECT OF ADDITIONAL COLD WATER STORAGE IN SHASTA ON ANADROMOUS FISH SURVIVAL

SIMULATION MODELS II-1

CALSIM II II-1

Water Temperature Models II-2

Salmon Mortality Model II-3

SALMON MORTALITY II-3

Estimated Salmon Mortality II-4

Estimated Number of Salmon Saved II-4

Population Increase II-4

FINDINGS II-12

CHAPTER III EFFECT OF MINIMUM FLOW INCREASES ON ANADROMOUS FISH HABITAT AND SURVIVAL

EXISTING CONDITIONS III-1

Flow Requirements III-1

Distribution of Spawning Within the Study Reach III-3

METHODOLOGY III-4

Flow Modeling III-4

HEC-RAS Model Results III-6

FINDINGS III-7

TABLES

Table II-1 Water Year Type Distribution used in Modeling II-4

Table II-2 Sacramento River Percent Salmon Mortality by Dam Raise Scenario and Year Type II-7

Table II-3 Sacramento River Salmon Mortality by Dam Raise Scenario and Year Type ... II-8

Table II-4 Sacramento River Relative Population Saved by Dam Raise Scenario and Year Type II-9

Table II-5 Population Increase per Life Cycle II-10

Table II-6 Population Over 50-Year Period II-11

Table III-1 Average Daily Outflow from Keswick Dam (1998 to present) III-2

Table III-2 Estimated Redd Distribution of Winter-Run Chinook Salmon III-3

Table III-3 HEC-RAS Analysis Subreaches III-6

Table III-4 Summary of HEC-RAS Minimum Flow Simulation Results III-7

Table III-5 HEC-RAS Minimum Flow Simulation Results by Subreach III-8

Table III-6 Potential Increases in Aquatic Habitat with 6.5-Foot and 18.5-Foot Dam Raise Scenarios III-9

CHAPTER I
INTRODUCTION

Anadromous fish survival is one of the primary objectives of the Shasta Lake Water Resources Investigation (SLWRI). Two ways anadromous fish survival may be improved include providing additional cold water in Shasta to regulate river water temperatures, and providing additional aquatic habitat in the Sacramento River. Detailed studies would be required to accurately quantify the intricate, and often unknown, links between salmon mortality and the numerous environmental factors that affect their lives. Because that level of study is not possible at this time, this appendix presents the general findings of two initial evaluations:

- **Chapter II** discusses the estimated relative impacts to the chinook salmon population along the upper Sacramento River associated with enlarging the cold water pool in Shasta Reservoir.
- **Chapter III** discusses the relationship between minimum flows in the Sacramento River, aquatic habitat, and anadromous fish survival.

These assessments were performed in support of feasibility-level plan formulation and concept plans evaluation efforts of the SLWRI. Several alternative dam raise scenarios are referenced in this documentation. Additional information on the alternative dam raise scenarios under consideration by the SLWRI can be found in the main body of the Initial Alternatives Information Report (IAIR).

METHODOLOGY

The health and survival of anadromous fish are dependent on numerous environmental factors, including water temperature, available habitat, river flows, seasonal hydrologic conditions, spawning substrate, ocean conditions, and many more. This complex interaction makes it difficult to predict how changes to one or more environmental condition will effect their survival. This section discusses preliminary analyses conducted to assess the potential effects on anadromous fish survival of two important factors: cold water storage in Shasta Lake, and minimum flows on the upper Sacramento River.

Currently, there are no existing tools that take into account all of the major influences on anadromous fish survival in the upper Sacramento River. Consequently, preliminary analyses were performed that evaluated cold water storage and minimum stream flows separately. The effects of additional cold water storage were assessed using procedures and models developed previously by the United States Department of the Interior, Bureau of Reclamation (Reclamation) and the United States Fish and Wildlife Service (USFWS) to evaluate fish mortality related to the temperature control device (TCD). The potential benefits of increases in minimum stream flows were assessed using a hydraulic model of the upper Sacramento River developed previously by the California Department of Water Resources (DWR). While these preliminary assessments do not take into consideration every factor affecting anadromous fish survival, they provide a means of comparing potential actions to address this primary objective of the SLWRI.

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER II
EFFECT OF ADDITIONAL COLD WATER STORAGE IN SHASTA ON ANADROMOUS FISH SURVIVAL

An assessment was conducted of the estimated relative impacts to the chinook salmon population along the upper Sacramento River associated with enlarging the cold water pool in Shasta Reservoir. The assessment followed a process conducted by Reclamation and USFWS to examine the impacts on water temperature and fish mortality related to the TCD. This process is described in the 1991 final planning report by Reclamation titled Planning Report/Final Environmental Statement, Shasta Outflow Temperature Control, Shasta County, California (TCD-ES). Reference is made to that report for a detailed description of the analysis process.

Below are the results of the assessment conducted for each of the four runs of salmon under the no-action and baseline conditions and five dam raise scenarios similar to the concept plans contained in Chapter VII of the Initial Alternatives Information Report. They include the following:

- 6.5-foot Raise (Min. Pool) similar to Plan AFS-1
- 6.5-foot Raise (AFRP Flows) similar to Plan AFS-2
- 6.5-foot Raise (WS) similar to Plan WSR-1
- 18.5-foot Raise (WS) similar to Plan WSR-2
- 18.5-foot Raise with conjunctive water management (WS) similar to Plan WSR-4
- 200-foot Raise (WS) similar to Plan WSR-3

The first two dam raise scenarios have a fisheries focus, while the last four scenarios have a water supply (WS) focus. Information about the projected mortality and benefits to the fishery of these plans can be used to assess similar impacts of the other concept plans considered.

SIMULATION MODELS

Three basic modeling tools were used to derive the estimated impacts of various increases and operations of Shasta Dam on the salmon fish populations primarily in the Sacramento River. They included CALSIM II, Sacramento River Water Temperature Model, and the Salmon Mortality Model. Following is a highlight of each.

CALSIM II

CALSIM is a water allocation simulation model. It is a statewide panning model for the operation, management, and development of the Central Valley Project (CVP) and State Water Project (SWP). It accounts for operational objectives, physical constraints, legal and institutional agreements, and the status of established physical conditions. Its applications primarily consist of evaluating system conditions under simulated existing (or without-project conditions) and then under simulated with-project conditions. It is useful in evaluating water supply, hydropower, water temperature, in-stream flows, recreation, and environmental impacts. Estimated benefits (accomplishments) or impacts of a potential project are measured as the difference between the no-action and with-project conditions. It is a monthly model currently constructed on a 73-year period analysis (1922 - 1994). A description of the CALSIM model and its application on the concept plans included in this IAIR is contained in **Appendix A**.

Water Temperature Models

Water temperature models are used in this IAIR to assess temperature changes along the Sacramento River, major tributaries, and Stanislaus River resulting primarily from changes in the volume of the cold water pool in Shasta Reservoir and changes in the volume and temperatures from Shasta Dam. The Reclamation temperature model consists of reservoir and river modeling components:

- **Reservoir Component -** The reservoir temperature model was developed by the Corps of Engineers. It simulates the one-dimensional, vertical distribution of reservoir water temperature using monthly input data on initial storage and temperature conditions, inflow, outflow, evaporation, radiation, and average air temperature. The reservoir temperature model outputs monthly mean vertical temperature profiles and release temperature for Trinity, Whiskeytown, Shasta, Oroville, Folsom, New Melones, and Tulloch reservoirs based on hydrologic an climatic input data.
- **River Component -** The river temperature model receives output from the reservoir model and calculates temperature changes in the four re-regulating reservoirs (Lewiston, Keswick, Thermalito, and Natoma). The river model also computes temperatures at various selected locations in each river. It is also a one-dimensional model, in the longitudinal direction, and assumes fully mixed river cross sections. The effect of tributary inflow on river temperature is computed by mass balance.

The TCD at Shasta, Oroville, and Folsom dams can selectively withdraw water from different reservoir levels to provide downstream temperature control. The TCDs are generally operated to conserve cold water for the summer and fall months when river temperatures become critical for fisheries. The models simulate the TCD operations by making upper level releases in the winter and spring, mid-level releases in the late spring and summer, and low level releases in the late summer and fall.

The temperature models for the Sacramento, Feather, and American rivers are documented in a June 1990 publication by Reclamation title USBR Monthly Temperature Model-Sacramento River Basin. The Trinity and Stanislaus Rivers temperature models are documented in Reclamation's 1979 report titled Mathematical Model Investigation: Trinity Dam Multilevel Outlet Elevation, Trinity River Temperature Prediction Study and June 1997 report titled Stanislaus River Basin Temperature Model, respectively. Temperature changes in the downstream regulating reservoirs Lewiston, Keswick, Thermalito, Natomas, and Goodwin are computed from equilibrium temperature decay equations in the reservoir models, which are similar to the river model equations. The river temperature models output temperatures at 3 locations on the Trinity River from Lewiston Dam to the North Fork, 12 locations on the Sacramento River from Keswick Dam to Freeport, 12 locations on the Feather River from Oroville Dam to the mouth, 9 locations on the American River from Nimbus Dam to the mouth, and 8 locations on the Stanislaus River from Goodwin Dam to the mouth. The river temperature calculations are based on regulating reservoir release temperatures, river flows, and climatic data. Monthly mean historical air temperatures for the 73-year period and other long-term average climatic data for Trinity, Shasta, Whiskeytown, Redding, Red Bluff, Colusa, Oroville, Marysville, Folsom, Sacramento, New Melones, and Stockton were obtained from Weather Bureau records and used to represent climatic conditions for the five river systems.

Salmon Mortality Model

The Reclamation salmon mortality model is described in the TCD-ES and 1994 Central Valley Project Improvement Act-Programmatic Environmental Impact Statement (CVPIA-PEIS). Temperature-exposure mortality criteria for three life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) are used along with the spawning distribution data and output from the river temperature models to compute salmon spawning losses in percent. Temperature units (TU), defined as the difference between river temperatures and 32° F, are calculated daily by the mortality model and used to track life-stage development. Eggs are assumed to hatch upon exposure to 750 TUs following fertilization. Fry are assumed to emerge from the gravel after exposure to 750 TUs following egg hatching into the preemergent fry stage. The temperature mortality rates for fertilized eggs, the most sensitive life stage, range from 8 percent mortality in 24 days at 57° F to 100 percent mortality in 7 days at 64° F or above. Most salmon spawning generally occurs above the North Fork on the Trinity River, above Red Bluff on the Sacramento River for all four salmon runs, above Honcut Creek on the Feather River, above Watt Avenue on the American River, and above Riverbank on the Stanislaus River. Fall-run salmon spawning usually occurs from mid-October through December, peaking about mid-November. Winter-run salmon usually spawn on the Sacramento River during May-July, and spring-run salmon during August-October.

SALMON MORTALITY

The salmon mortality model was run for each of the six conditions above, using critical input information from the CALSIM and temperature models. The analysis is also based on using year 2020 level hydrologic conditions. Primary output of the mortality model is estimated percent mortality for each of the four runs of salmon in the upper Sacramento River as a function of water year conditions. These conditions are defined as wet, above normal, below normal, dry, and critically dry conditions. Definitions of water year, or type, is based on the Sacramento Valley 40-30-30 Index developed by the State Water Regional Control Board (SWRCB) as part of the San Francisco Bay/Sacramento-San Joaquin Delta (Bay-Delta) regulatory activities. **Table II-1** shows the distribution of these conditions during the 73-year period of analysis in the CALSIM, temperature, and mortality models using the 40-30-30 Index.

The estimated percent mortality using the Salmon Mortality Model of early life stages for the four salmon runs under the no-action condition and each of the five dam raise scenarios for each of the representative water year types is shown in **Figure II-1**. For information purposes, **Figure II-2** shows the estimated percent mortality of early life stages of salmon under the six conditions also for each of the water year types on the Trinity, Feather, American, and Stanislaus rivers. As can be seen, in essentially all cases there is an expected decline in mortality for each of the dam raise options over the no-action condition. The estimated percentages of mortality for each water year type, salmon run, and evaluation condition for the Sacramento River in **Figure II-1** is also shown in **Table II-2**.

TABLE II-1
WATER YEAR TYPE DISTRIBUTION USED IN MODELING

Water Year Type[1]	Occurrences[2]
Wet	21
Above Normal	10
Below Normal	14
Dry	16
Critically Dry	12
Total	**73**

[1] Based on 40-30-30 water year type.
[2] Occurrences in 73-year period of analysis (1921-1994).

Estimated Salmon Mortality

Table II-3 lists projected salmon mortality by water year type and seasonal run based on an estimated initial population for the no-action condition and each of the five dam raise scenarios. The initial salmon population in the table is based on the average number of chinook returning past the Red Bluff Diversion Dam (RBDD) near Red Bluff from 1996 through 2001. The projected number of spawners killed by year type in **Table II-3** is the product of the initial returning population and estimated percent mortality for each analysis condition in **Table II-2**.

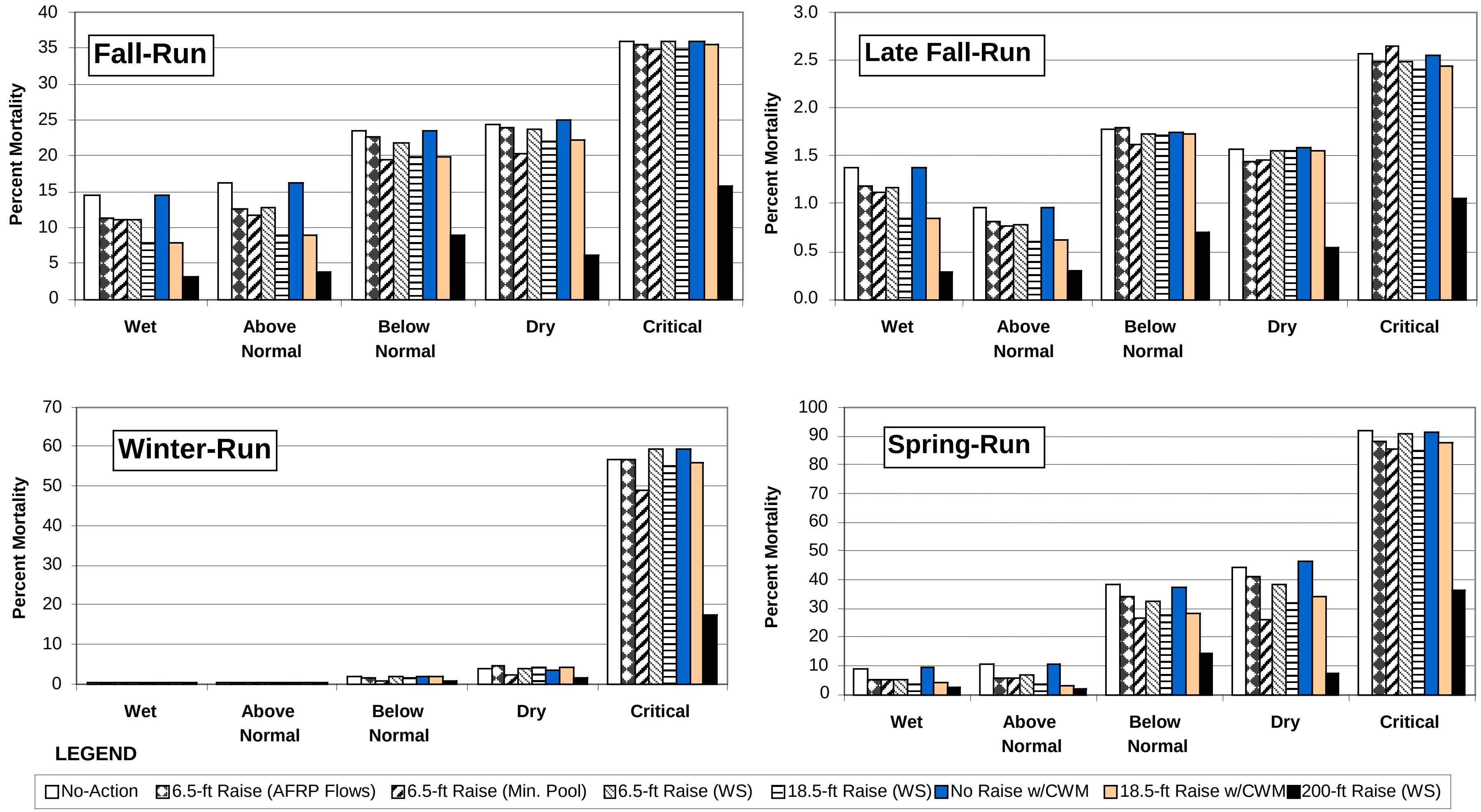
Estimated Number of Salmon Saved

Table II-4 lists the projected number of salmon saved by water year type and salmon run. The projected number of salmon saved is the difference between the estimated population killed under the No-Action and five dam raise scenarios being considered (**Table II-3)**.

The figures in **Table II-4** represent the projected number of salmon saved is in excess of the Baseline Condition (with the Baseline Condition set at zero). In actuality, however, the Baseline Condition over the life of a project will change and, based on information in the 1991 TCD-ES, the likely future number of salmon will increase primarily because of the TCD. Hence, the projected number of salmon saved estimated in this assessment would be in excess of this Baseline Condition. Further, the total number of salmon saved in **Table II-4** represents a weighted average between the various year types. It is the sum of the products of salmon saved by water year type and the number of years in the year type divided by the total number of years in the analysis (73-years).

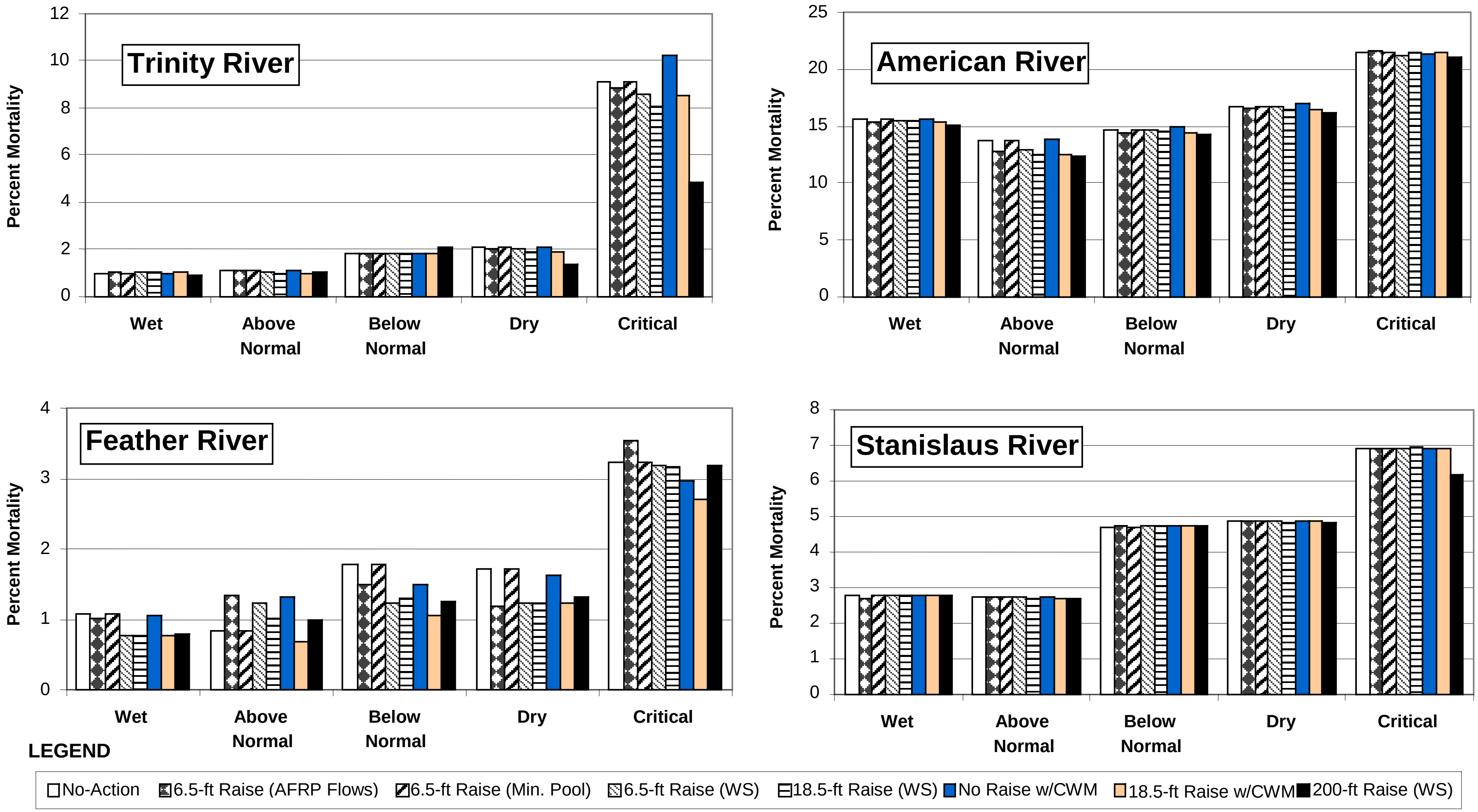
Population Increase

An estimate was made of the increase in salmon populations resulting from the various dam raise options over the Baseline Conditions. **Table II-5** shows the estimated increase in population of each run of salmon for each of the dam raise scenarios. For example, for the 200-foot dam raise option, of the estimated 49,000 initial returning fall-run salmon, about 7,400 salmon would be saved (15 percent of the total run) over the Baseline Condition. Of the total 62,600 returning salmon, about 7,860 salmon (12.6 percent of all four runs) would be saved over the Baseline Condition.



Based on year 2020 level water demands and 40-30-30 water year type.

Figure II-1 – Estimated mortality in the Sacramento River for fall-, late-fall,-winter-, and spring-run chinook salmon for the No-Action and five dam raise scenarios.



Based on year 2020 level water demands and 40-30-30 water year type.

Figure II-2 – Estimated mortality of chinook salmon in the Trinity, Feather, American, and Stanislaus rivers for the No-Action and five dam raise scenarios.

TABLE II-2
SACRAMENTO RIVER PERCENT SALMON MORTALITY BY DAM RAISE SCENARIO AND YEAR TYPE

Run / Dam Raise Scenario	Percent Mortality By Water Year Type [1]				
	Wet	Above Normal	Below Normal	Dry	Critical
Fall-Run					
No Action [2]	14.5	16.2	23.6	24.4	36.0
6.5-ft Raise (Min. Pool)	11.0	11.8	19.4	20.3	34.8
6.5-ft Raise (AFRP Flows)	11.2	12.6	22.5	23.9	35.4
6.5-ft Raise (WS)	11.0	12.7	21.7	23.7	36.0
18.5-ft Raise (WS)	7.8	9.0	19.8	21.9	34.8
18.5-ft Raise w/CWM (WS)	7.9	9.0	19.9	22.3	35.4
200-ft Raise (WS)	3.0	3.8	9.0	6.2	15.7
Late-Fall-Run					
No Action [2]	1.4	1.0	1.8	1.6	2.6
6.5-ft Raise (Min. Pool)	1.1	0.8	1.6	1.5	2.6
6.5-ft Raise (AFRP Flows)	1.2	0.8	1.8	1.4	2.5
6.5-ft Raise (WS)	1.2	0.8	1.7	1.5	2.5
18.5-ft Raise (WS)	0.9	0.6	1.7	1.5	2.4
18.5-ft Raise w/CWM (WS)	0.9	0.6	1.7	1.6	2.4
200-ft Raise (WS)	0.3	0.3	0.7	0.5	1.1
Winter-Run					
No Action [2]	0.3	0.3	1.8	3.7	56.6
6.5-ft Raise (Min. Pool)	0.2	0.3	0.8	2.2	48.8
6.5-ft Raise (AFRP Flows)	0.2	0.3	1.6	4.6	56.5
6.5-ft Raise (WS)	0.3	0.3	1.9	3.7	59.3
18.5-ft Raise (WS)	0.3	0.2	1.6	4.2	54.9
18.5-ft Raise w/CWM (WS)	0.3	0.2	1.7	4.1	56.0
200-ft Raise (WS)	0.2	0.1	0.7	1.4	17.3
Spring Run					
No Action [2]	8.9	10.7	38.2	44.2	91.8
6.5-ft Raise (Min. Pool)	5.3	5.4	26.8	25.8	85.4
6.5-ft Raise (AFRP Flows)	5.4	5.9	33.9	41.3	88.0
6.5-ft Raise (WS)	5.2	6.5	32.7	38.3	91.1
18.5-ft Raise (WS)	3.8	3.4	27.6	31.9	85.3
18.5-ft Raise w/CWM (WS)	3.9	3.3	28.2	34.1	87.8
200-ft Raise (WS)	2.6	2.1	14.1	7.3	35.9

Notes:
[1] Based on year type 40-30-30 Index and year 2020 level demands.
[2] No Action = No project, existing conditions with year 2020 level demands.

TABLE II-3
SACRAMENTO RIVER SALMON MORTALITY BY DAM RAISE SCENARIO AND YEAR TYPE

Run	**Number of Spawners Killed**[1]				
Dam Raise Scenario	**Wet**	**Above Normal**	**Below Normal**	**Dry**	**Critical**
Fall-Run					
Initial Returning Population[2]	49,000				
No Action	7,107	7,952	11,545	11,956	17,638
6.5-ft Raise (Min. Pool)	5,405	5,773	9,485	9,936	17,047
6.5-ft Raise (AFRP Flows)	5,509	6,155	11,044	11,722	17,334
6.5-ft Raise (WS)	5,397	6,241	10,632	11,621	17,631
18.5-ft Raise (WS)	3,833	4,420	9,686	10,740	17,048
18.5-ft Raise w/CWM (WS)	3,859	4,412	9,747	10,932	17,340
200-ft Raise (WS)	1,484	1,844	4,392	3,024	7,713
Late-Fall-Run					
Initial Returning Population[2]	10,000				
No Action	138	96	178	158	256
6.5-ft Raise (Min. Pool)	112	76	163	146	264
6.5-ft Raise (AFRP Flows)	118	82	180	144	249
6.5-ft Raise (WS)	116	79	172	155	249
18.5-ft Raise (WS)	85	61	172	155	240
18.5-ft Raise w/CWM (WS)	85	61	172	155	244
200-ft Raise (WS)	29	30	69	55	106
Winter-Run					
Initial Returning Population[2]	2,800				
No Action	7	8	50	105	1,585
6.5-ft Raise (Min. Pool)	6	9	23	62	1,366
6.5-ft Raise (AFRP Flows)	7	9	46	128	1,583
6.5-ft Raise (WS)	7	9	52	103	1,661
18.5-ft Raise (WS)	7	6	44	117	1,538
18.5-ft Raise w/CWM (WS)	7	7	48	115	1,567
200-ft Raise (WS)	5	4	18	39	486
Spring-Run					
Initial Returning Population[2]	800				
No Action	72	85	305	353	734
6.5-ft Raise (Min. Pool)	42	43	214	206	683
6.5-ft Raise (AFRP Flows)	43	47	271	330	704
6.5-ft Raise (WS)	42	52	262	307	729
18.5-ft Raise (WS)	30	27	221	255	682
18.5-ft Raise w/CWM (WS)	31	26	225	273	703
200-ft Raise (WS)	21	17	113	59	288

Notes:
[1] Percent mortality times initial returning population.
[2] Based on average annual returning population for years 1996 through 2001.

TABLE II-4
SACRAMENTO RIVER RELATIVE POPULATION SAVED BY DAM RAISE SCENARIO AND YEAR TYPE

Item	Number of Spawners Saved[1]					Weighted Total No. Saved
	Wet	Above Normal	Below Normal	Dry	Critical	
No. Of Years In Year Type[2]	21	10	14	16	12	73
Fall-Run						
Baseline Condition[3]	0	0	0	0	0	0
6.5-ft Raise (Min. Pool)	1,702	2,179	2,060	2,020	591	1,723
6.5-ft Raise (AFRP Flows)	1,597	1,796	501	234	303	903
6.5-ft Raise (WS)	1,710	1,711	914	335	7	976
18.5-ft Raise (WS)	3,273	3,532	1,860	1,215	590	2,145
18.5-ft Raise w/CWM (WS)	3,248	3,539	1,798	1,024	298	2,037
200-ft Raise (WS)	5,623	6,107	7,153	8,932	9,924	7,415
Late-Fall-Run						
Baseline Condition[3]	0	0	0	0	0	0
6.5-ft Raise (Min. Pool)	26	20	16	11	-9	14
6.5-ft Raise (AFRP Flows)	21	14	-1	14	7	12
6.5-ft Raise (WS)	22	17	6	3	7	12
18.5-ft Raise (WS)	53	35	7	3	16	25
18.5-ft Raise w/CWM (WS)	53	35	6	2	12	24
200-ft Raise (WS)	109	66	109	103	150	109
Winter-Run						
Baseline Condition[3]	0	0	0	0	0	0
6.5-ft Raise (Min. Pool)	1	-1	27	43	220	51
6.5-ft Raise (AFRP Flows)	0	-1	5	-23	2	-4
6.5-ft Raise (WS)	0	-1	-1	2	-75	-12
18.5-ft Raise (WS)	0	2	6	-12	48	6
18.5-ft Raise w/CWM (WS)	0	1	2	-10	19	1
200-ft Raise (WS)	2	4	32	66	1100	203
Spring-Run						
Baseline Condition[3]	0	0	0	0	0	0
6.5-ft Raise (Min. Pool)	29	42	91	147	51	72
6.5-ft Raise (AFRP Flows)	29	38	34	23	30	30
6.5-ft Raise (WS)	30	33	43	47	6	33
18.5-ft Raise (WS)	41	58	84	98	52	66
18.5-ft Raise w/CWM (WS)	41	59	80	80	32	58
200-ft Raise (WS)	51	68	192	295	447	199

Notes:
[1] Number of fish killed for dam raise options less number killed for baseline by year type.
[2] Number of each year type in the 73- year period of analysis (1921-1994).
[3] The Baseline is set to zero, but will change over time based on the influence of the TCD and other factors.

The estimated salmon saved, or population increased, in **Table II-5** is for one returning life cycle, which is estimated at 3 years. **Table II-6** shows the projected population increase over a 50-year period (project life). The incremental population values shown in the table for each salmon run is the initial returning population increased by the total salmon saved per life cycle from **Table II-5** compounded over the life of the project (17 occurrences). The increase over baseline condition value is the incremental population less the initial population. The average annual increase in population is the increase in population over baseline condition divided by the project life. The total, increase in population, or average annual increase in population in the table, is the sum of the individual values for each salmon run.

TABLE II-5
POPULATION INCREASE PER LIFE CYCLE

Initial Plan	Population Increase per Life Cycle[1] Fall-Run	Late Fall-Run	Winter-Run	Spring-Run	Total
Initial Returning Population [2]	49,000	10,000	2,800	800	62,600
6.5-ft Raise (Min. Pool)					
Total Saved Per Life Cycle	1,723	14	51	72	1,860
Percent Increase [3]	3.5	0.1	1.8	9.0	3.0
6.5-ft Raise (AFRP Flows)					
Total Saved Per Life Cycle	903	12	-4	30	941
Percent Increase [3]	1.8	0.1	-0.1	3.8	1.5
6.5-ft Raise (WS)					
Total Saved Per Life Cycle	976	12	-12	33	1,008
Percent Increase [3]	2.0	0.1	-0.4	4.1	1.6
18.5-ft Raise (WS)					
Total Saved Per Life Cycle	2,145	25	6	66	2,243
Percent Increase [3]	4.4	0.2	0.2	8.3	3.6
18.5-ft Raise w/CWM (WS)					
Total Saved Per Life Cycle	2,037	24	1	58	2,120
Percent Increase [3]	4.2	0.2	0.1	7.2	3.4
200-ft Raise (WS)					
Total Saved Per Life Cycle	7,415	109	203	199	7,925
Percent Increase [3]	15.1	1.1	7.2	24.9	12.7

Notes:
[1] Based on 3-year life cycle of Sacramento River chinook.
[2] Average annual returning population for years 1996 through 2001.
[3] Percent increase over initial returning population.

TABLE II-6
POPULATION OVER 50-YEAR PERIOD

Initial Plan	Population Over 50 Years[1] Fall-Run	Late Fall-Run	Winter-Run	Spring-Run	Total
Initial Returning Population[2]	49,000	10,000	2,800	800	62,600
6.5-ft Raise (Min. Pool)					
Incremental Population In 50 Years [3]	88,176	10,246	3,802	3,481	105,706
Increase Over Without-Project[4]	39,176	246	1,002	2,681	43,106
Percent Increase	80	2	36	335	69
Average Annual Increase	784	5	20	54	862
6.5-ft Raise (AFRP Flows)					
Incremental Population In 50 Years [3]	66,832	10,200	2,733	1,499	81,265
Increase Over Without-Project[4]	17,832	200	-67	699	18,665
Percent Increase	36	2	-2	87	30
Average Annual Increase	357	4	-1	14	373
6.5-ft Raise (WS)					
Incremental Population In 50 Years [3]	68,522	10,199	2,595	1,575	82,891
Increase Over Without-Project[4]	19,522	199	-205	775	20,291
Percent Increase	40	2	-7	97	32
Average Annual Increase	390	4	-4	16	406
18.5-ft Raise (WS)					
Incremental Population In 50 Years [3]	101,526	10,427	2,912	3,085	117,949
Increase Over Without-Project[4]	52,526	427	112	2,285	55,349
Percent Increase	107	4	4	286	88
Average Annual Increase	1,051	9	2	46	1,107
18.5-ft Raise w/CWM (WS)					
Incremental Population In 50 Years [3]	97,939	10,408	2,825	2,622	113,795
Increase Over Without-Project[4]	48,939	408	25	1,822	51,195
Percent Increase	100	4	1	228	82
Average Annual Increase	979	8	1	36	1,024
200-ft Raise (WS)					
Incremental Population In 50 Years [3]	537,760	12,017	9,177	34,870	593,824
Increase Over Without-Project[4]	488,760	2,017	6,377	34,070	531,224
Percent Increase	997	20	228	4259	849
Average Annual Increase	9,775	40	128	681	10,624

Notes:
[1] Population increases over baseline condition.
[2] Based on average annual returning population for years 1996 through 2001.
[3] Based on population increase for each return cycle over 50 years (17 occurrences).
[4] Net increase over conditions including increases due to TCD.

FINDINGS

This evaluation indicates a general correspondence between increases in storage space in Shasta Reservoir and increases in the population of chinook salmon in the upper Sacramento River. Raising Shasta Dam 200 feet provides the greatest quantity of cold water and, therefore, has the greatest potential to benefit the salmon population throughout the primary and secondary study area. For each dam raise scenario evaluated, the largest increase in salmon population is projected to occur to the fall-run salmon, with the smallest increases to the late fall and winter-runs.

It should be noted that there are limitations in the use of the CALSIM, temperature models, and mortality model. The main limitation of CALSIM and the temperature models used in the study is the monthly simulation time-step. Mean monthly flows and temperatures do not define daily variations that could occur in the rivers due to dynamic flow and climatic conditions. However, monthly results are still useful for general comparison of alternatives. The temperature models are also unable to accurately simulate certain aspects of the actual operations strategies used when attempting to meet temperature objectives, especially on the upper Sacramento River. To account for the short-term variability and the operational flexibility of the system to respond to changing conditions, cooler water than that indicated by the model is released in order to avoid exceeding the required downstream temperature target. There is also uncertainty regarding performance characteristics of the Shasta Dam TCD. Due to the hydraulic characteristics of the TCD, including leakage, overflow, and performance of the side intakes, the model releases are cooler than can be achieved in real-time operations; therefore, a more conservative approach is taken in real-time operations that is not fully represented by the models.

The salmon mortality model is limited to temperature effects on early life stages of chinook salmon. It does not evaluate potential direct or indirect temperature impacts on later life stages, such as emergent fry, smolts, juvenile out-migrants, or adults. Also, it does not consider other factors that may affect salmon mortality, such as in-stream flows, gravel sedimentation, diversion structures, predation, ocean harvest, etc. Since the salmon mortality model operates on a daily time-step, a procedure is required to use the monthly temperature model output. The salmon model computes daily temperatures based on linear interpolation between the monthly temperatures, which are assumed to occur on the 15th day of the month.

However, over the long term, it is believed the above tools and approach are a valid approximation of the relative influences that increasing the storage space in Shasta Reservoir will have on the salmon population in the upper Sacramento River. Further, as noticed in **Figure II-2**, increasing storage in Shasta Reservoir tends to benefit a reduced mortality of salmon in other tributaries to the Sacramento River including the Trinity, Feather, and American rivers.

CHAPTER III
EFFECT OF MINIMUM FLOW INCREASES ON ANADROMOUS FISH HABITAT AND SURVIVAL

Several of the concept plans developed for the SLWRI utilize expanded storage at Shasta Reservoir to increase minimum flows on the upper Sacramento River for anadromous fish. A preliminary assessment was performed to evaluate the potential for aquatic habitat improvements resulting from increasing minimum instream flows. This initial assessment does not provide a means of evaluating the quality of the new aquatic habitat, or whether the new habitat would be suitable for spawning, rearing, or other life stages of anadromous fish. While this assessment can not quantify the benefits to anadromous fish in terms of fish mortality or long-term survival, the assessment does provide an initial means of comparing the relative benefits of potential flow increases on the upper Sacramento River. Future studies will be required to better quantify the benefits of flow increases to chinook salmon and other anadromous fish on the upper Sacramento River.

EXISTING CONDITIONS

This section describes existing conditions for flow requirements and distribution of spawning habitat in the study reach.

Flow Requirements

Listing of the winter-run chinook salmon under the Endangered Species Act (ESA) resulted in biological opinions (BOs) by the National Marine Fisheries Service (NMFS, now National Oceanic and Atmospheric Administration (NOAA) Fisheries), USFWS and the California Department of Fish and Game (CDFG) that placed constraints on CVP and SWP operations at Shasta Dam. The 1993 winter-run chinook salmon BO issued by NMFS requires minimum releases from Keswick Dam of 3,250 cubic feet per second (cfs) between October 1 and March 31. These minimum flows are intended to promote successful rearing and safe downstream passage for winter-run chinook salmon. However, flows between 5,000 cfs and 5,500 cfs during this same period produce conditions that are more ideal for anadromous fish. Higher instream flows would provide access to additional spawning and rearing habitat sites, extend the area of suitable habitat farther downstream, and generally improve aquatic and riparian habitat conditions along the river.

Average daily outflow from Keswick Dam between 1998 and the present is illustrated in **Figure III-1** and summarized in **Table III-1** for the months of October through March. Also listed in the table are the number of days in which the average flow was less than 3,250 cfs and 5,500 cfs. The flows reported are daily averages and do not indicate every instance that flows fell below 3,250 cfs over a 24-hour period (or the duration of these occurrences). However, the information provides insight into the success of operators in maintaining healthy flows for anadromous fish in the upper Sacramento River.

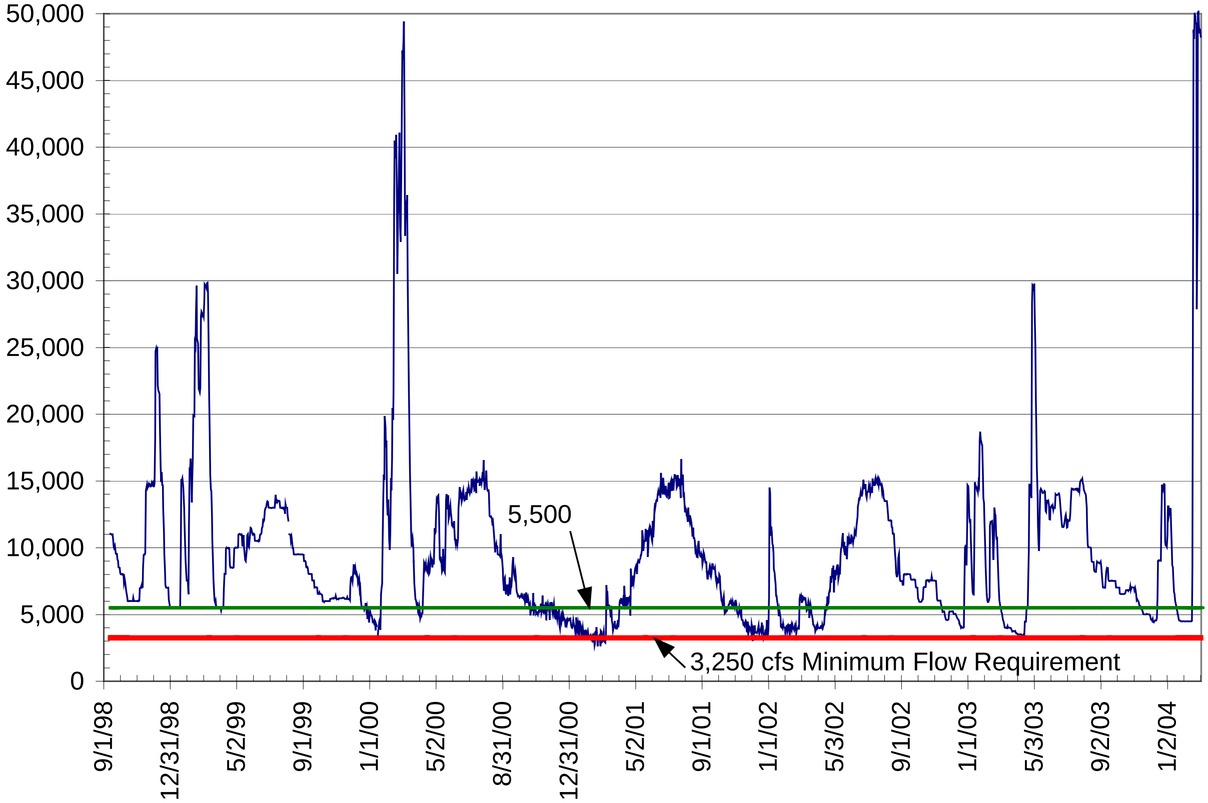


Figure III-1 – Keswick outflow, 1998 to the present.

TABLE III-1
AVERAGE DAILY OUTFLOW FROM KESWICK DAM (1998 TO PRESENT)

	October	November	December	January	February	March
Average	6,437	6,425	7,224	7,921	14,239	11,098
Maximum	8,078	14,885	24,954	19,874	50,151	49,418
Minimum	4,923	3,520	3,004	3,049	2,611	2,898
No. of days <3,250 cfs	0	0	2	3	7	5
No. of days <5,500 cfs	14	78	104	79	70	71

Source: California Data Exchange Center (CDEC)

In addition to minimum instream flows, flow fluctuations are also regulated on the upper Sacramento River. Rapid reductions in flow can dewater spawning beds and strand juveniles. The BO requires that flow reductions be conducted during the night between July 1 and April 1. In addition, it specifies maximum rates of reduction during this period for specified flow levels. For example, flow reductions to 6,000 cfs cannot be decreased by more than 2.5 percent in a 1-hour period, and no more than 15 percent each night. Flow reductions between 5,999 cfs and 3,250 cfs must be reduced at lower rates because juveniles are more susceptible to stranding at lower flows.

Section 3406(b)(2) of the CVPIA directs Reclamation to dedicate and manage annually 800,000 acre-feet of CVP yield for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes and measures authorized by the CVPIA. These requirements are known as CVPIA b(2) Fish Actions. Portions of the 800,000 acre-feet have been utilized in the past to maintain flows on the upper Sacramento River.

Distribution of Spawning Within the Study Reach

Table III-2 presents the estimated redd (underwater gravel nest where eggs are deposited) distribution for winter run salmon within the study reach for the years 2000 through 2003, as reported by the CDFG. This survey confirms that the majority of winter-run salmon are spawning in the uppermost portion of the study reach, with the greatest numbers of redds reported in the subreach between the Highway 44 bridge and the Airport Road bridge. Hence, increasing minimum flows and creating additional aquatic habitat would likely have the greatest impact on anadromous fish survival within this reach. HEC-RAS results indicated that the adjacent subreach downstream showed the largest increase in aquatic habitat; its proximity to the reach used most by spawners could indicate a high potential for use if minimum flows are increased and more habitat becomes available. Similarly, increases in aquatic habitat between Bend Bridge and the RBDD would probably provide very minimal benefits to anadromous fish survival, as no spawning nests were detected downstream from Bend Bridge.

TABLE III-2
ESTIMATED REDD DISTRIBUTION OF WINTER-RUN CHINOOK SALMON

Reach	2000 Count	2000 % Total	2001 Count	2001 % Total	2002 Count	2002 % Total	2003 Count	2003 % Total
Keswick to ACID Dam	34	6%	484	35%	297	49%	578	66%
ACID Dam to HWY 44 Bridge	157	27%	215	15%	134	22%	151	17%
HWY44 Bridge to Airport Road Bridge	274	47%	624	45%	168	28%	143	16%
Airport Road Br to Balls Ferry Br	32	5%	55	4%	7	1%	3	0%
Balls Ferry Bridge to Battle Creek	35	6%	2	0%	3	0%	0	0%
Battle Creek to Jelly's Ferry	10	2%	2	0%	0	0%	0	0%
Jelly's Ferry to Bend Bridge	46	8%	8	1%	0	0%	0	0%
Bend Bridge to RBDD	0	0%	0	0%	0	0%	0	0%
TOTAL Upstream From RBDD	**588**		**1390**		**609**		**875**	

Source: California Department of Fish and Game aerial surveys.
Notes:
1. Percent Total represents the percentage of all redds surveyed upstream the RBDD occurring within a given reach. Does not include redds surveyed downstream from RBDD.

The distribution of redds within the study reach varies with each salmon run. **Figure III-2** illustrates the distribution of redds by approximate river reach (bars are placed within the center of each of the reaches identified in **Table III-2**) for each of the four runs. Note that the fall run is the only run with redds identified downstream from Red Bluff (not shown on the figure), hence the percentages are relatively low.

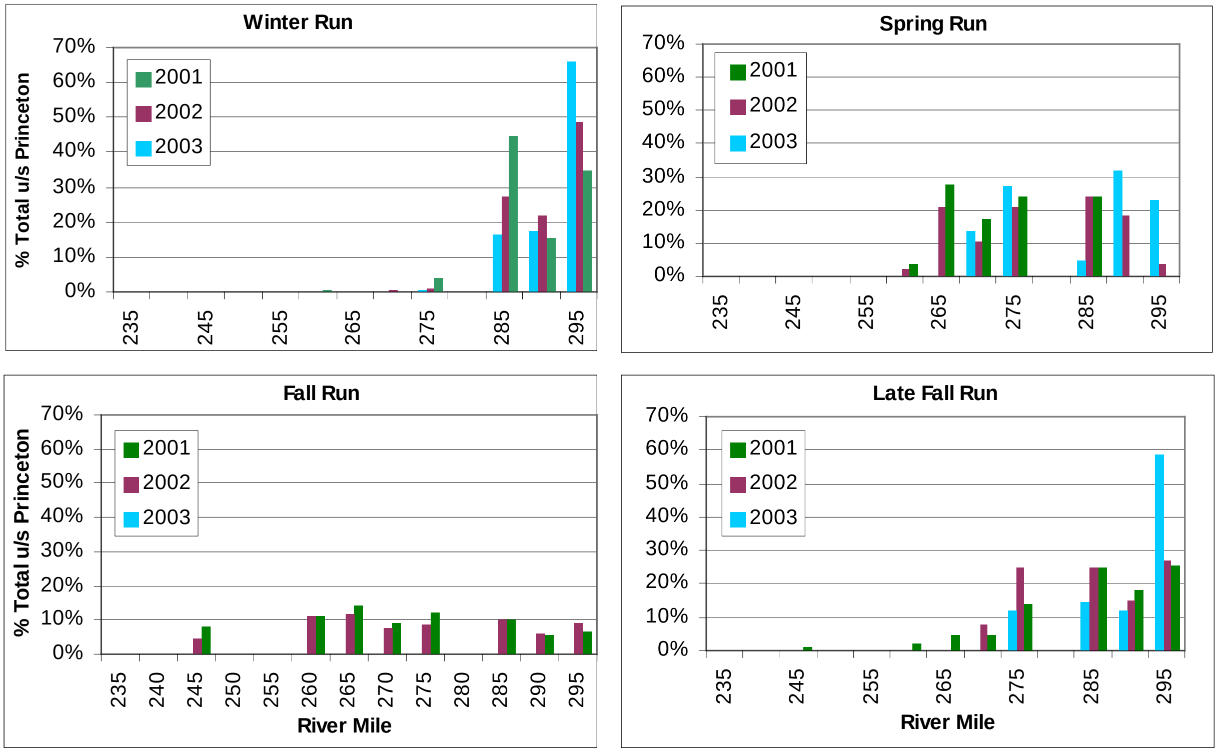


Figure III-2 – Distribution of redds by reach, 2000 through 2003.

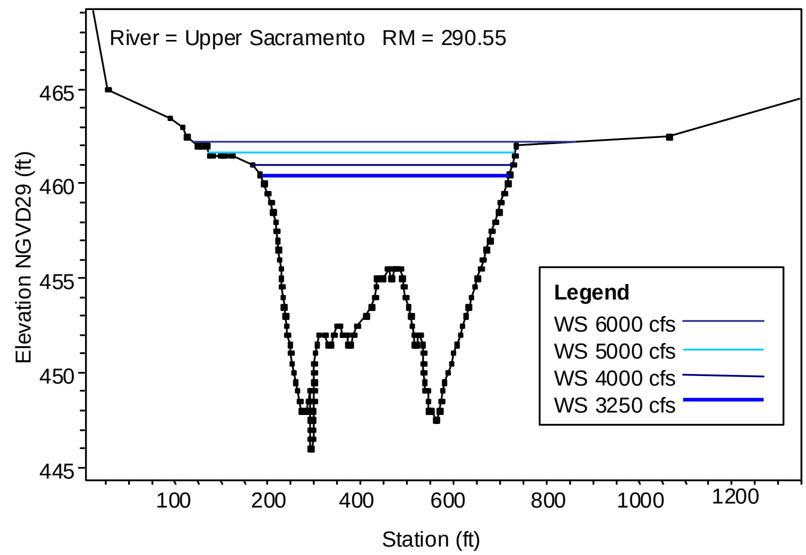
METHODOLOGY

A hydraulic model was used to evaluate channel conditions in the Sacramento River under a range of minimum flow increases. Model results were used to estimate changes in the total area of the channel that was inundated by the modeled flows. These changes were then used as an indicator of the potential benefits to anadromous fish of increasing minimum flows in the upper Sacramento River. This initial analysis does not consider the quality or suitability for spawning/rearing of the additional aquatic habitat.

Flow Modeling

This analysis used an HEC-RAS hydraulic model developed previously by DWR that extends from Woodson Bridge to Keswick. The model was created and calibrated for the purpose of developing water surface profiles for flood events. Within the study area between Red Bluff and Keswick, channel geometry data was developed from bathymetric surveys performed in 2001. Digital surfaces were developed from the bathymetric surveys, from which contours were generated at half-foot intervals and cross sections were subsequently cut. Cross section spacing in the HEC-RAS model varies from a few hundred feet to over 1 mile, and averages about 2,400 feet within the study reach. Bridge geometry was obtained from existing Federal Emergency Management Agency (FEMA) Flood Insurance Studies and as-built bridge plans.

No significant changes were made to the model for the purpose of this analysis. HEC-RAS 3.1.1 was used to simulate flows in a one-dimensional, steady-state regime. Flows ranging from the current 3,250 cfs minimum up to 6,000 cfs were simulated. Although the model was developed to simulate high flows, geometry data for the lower channel is sufficient, for the purpose of this initial study, to approximate increases in wetted channel area and depth. A sample cross section of the low flow channel is shown in **Figure III-3**.



Simulated water surfaces are shown for a cross section located upstream from HWY 299

Figure III-3 – Typical HEC-RAS cross section.

Five flows were simulated in the HEC-RAS model: 3,000, 3,250, 4,000, 5,000, and 6,000 cfs. The HEC-RAS model calculates various types of information regarding hydraulic conditions in the channel at each cross section for each of the simulated flows. For this analysis, information extracted from the model included wetted perimeter and hydraulic depth. Wetted perimeter is a measure the amount of the channel cross section that is inundated by a particular flow, measured in feet. Hydraulic depth is a measure of the average depth of flow in the channel, and is calculated by dividing the cross sectional flow area by the width of flow at the top of the water surface (top width). Wetted perimeter and top width are illustrated in **Figure III-4**.

Wetted perimeter was multiplied by the distance between cross sections to develop an approximation of the area of aquatic habitat for each simulated flow. These areas were summed for various reaches of the river to obtain an estimate of the number of acres of aquatic habitat available. It should be noted that this method only provides a rough estimate of aquatic habitat, and is highly dependent upon the (1) detail of the channel geometry, (2) spacing between the cross sections, and (3) the uniformity of the channel between cross sections. For this reason, it is more appropriate to discuss results in terms of percent change over existing conditions rather than in acres of aquatic habitat.

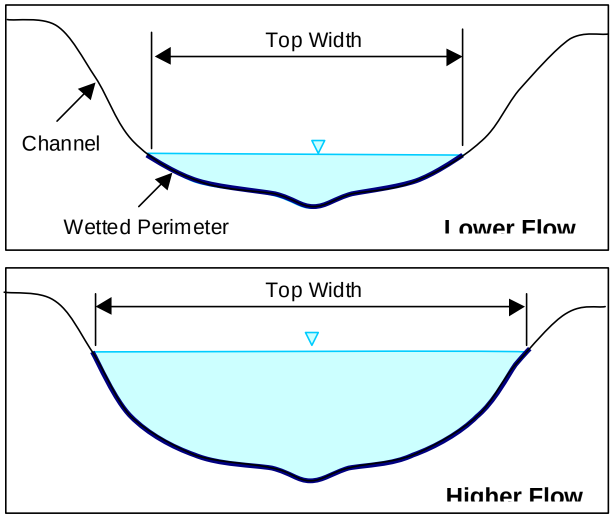


Figure III-4 – Changes in wetted perimeter and top width at different flows.

HEC-RAS Model Results

The geometry of the Sacramento River channel varies throughout the study area, ranging from narrow, entrenched sections to wider, shallow floodplain areas. In addition, the majority of winter-run chinook salmon spawn in the uppermost portion of the study area. For these reasons, the study area was divided into seven subreaches for evaluation of model results. To facilitate evaluation, these reaches coincide with the reaches reported in CDFG Biennial Reports on Sacramento River winter-run chinook salmon. The subreaches are listed in **Table III-3**.

TABLE III-3
HEC-RAS ANALYSIS SUBREACHES

Reach Name	Reach Boundaries (river miles, per model)	Reach Length (miles)
Keswick to ACID Dam	295.92 to 292.428	3.5
ACID Dam to HWY 44 Bridge	292.428 to 290.45	2.0
HWY44 Bridge to Airport Road Bridge	290.45 to 278.49	12.0
Airport Road Bridge to Balls Ferry Bridge	278.49 to 270.64	7.8
Balls Ferry Bridge to Battle Creek	270.64 to 268.6	2.0
Battle Creek to Jelly's Ferry	268.6 to 261.5	7.1
Jelly's Ferry to Bend Bridge	261.5 to 252.23	9.3
Bend Bridge to RBDD	252.23 to 237.54	14.7
	TOTAL	**58.4 miles**

A summary of the HEC-RAS modeling results for the entire study reach is provided in **Table III-4**, and a summary by subreach is provided in **Table III-5**. Results indicate that increasing the minimum flow target from 3,250 cfs to 5,500 cfs (identified as the ideal flow for winter-run) could potentially increase aquatic habitat in the study area by between 14 percent and 19 percent, corresponding to a potential increase of about 3,000 acres of aquatic habitat. The area that showed the greatest potential increases in aquatic habitat was the subreach from Airport Road Bridge to Balls Ferry Bridge. The subreaches between Battle Creek and Bend Bridge also showed notable increases. The subreach between Balls Ferry and Battle Creek showed the greatest increase in hydraulic depth; this could be significant because this subreach is comparatively shallow and has fewer deep pools. Hence, increases in depth could potentially improve aquatic habitat conditions within the subreach.

TABLE III-4
SUMMARY OF HEC-RAS MINIMUM FLOW SIMULATION RESULTS

Flow (cfs)	Average Wetted Perimeter (feet)	Estimated Total Wetted Area (acres)	% Change in Aquatic Habitat over 3,250 cfs
3,250	358	2,593	-
4,000	377	2,723	5%
5,000	405	2,946	14%
6,000	424	3,094	19%

FINDINGS

Various potential dam raises are under consideration in the SLWRI, as discussed in the previous section. All or a portion of the additional water storage afforded by these raises could be used to increase minimum flow requirements on the upper Sacramento River. **Table III-6** provides estimates of potential increases in aquatic area under two scenarios being considered: a 6.5-foot raise with an increase in minimum flow to 3,575 cfs, and an 18.5-foot raise with an increase in minimum flow to 5,194 cfs.

Based on the HEC-RAS simulation results, the table summarizes that aquatic habitat within the study area could potentially be increased by about 56 acres if the minimum flow were increased to 3,575 cfs in conjunction with a 6.5 feet dam raise. Similarly, 382 acres of additional aquatic habitat could potentially be created if the minimum flow were increased to 5,194 cfs in conjunction with an 18.5-foot raise.

TABLE III-5
HEC-RAS MINIMUM FLOW SIMULATION RESULTS BY SUBREACH

Flow (cfs)	Hydraulic Depth (feet) (Avg / Max / Min)[1]			Average Wetted Perimeter (feet)	Total Wetted Area[2] (acres)	% Change in Aquatic Habitat over 3,250 cfs
Keswick to ACID Dam (RM 295.92-292.428) 3.5 miles						
3,250	5.22	15.66	1.52	347	123	-
4,000	5.58	16.23	1.65	360	128	4%
5,000	6.01	16.91	1.78	373	133	8%
6,000	6.38	17.52	1.97	383	138	13%
ACID Dam to HWY 44 Bridge (RM 292.428-290.45) 2.0 miles						
3,250	3.80	8.21	1.75	367	77	-
4,000	3.99	8.60	1.73	398	80	5%
5,000	4.14	8.66	2.08	442	85	11%
6,000	4.32	8.70	2.41	476	93	21%
HWY44 Bridge to Airport Road Bridge (RM 290.45-278.49) 12.0 miles						
3,250	4.04	12.03	1.17	423	697	-
4,000	4.33	12.23	1.33	442	725	4%
5,000	4.70	12.66	1.53	459	757	9%
6,000	5.03	13.09	1.71	478	790	13%
Airport Road Bridge to Balls Ferry Bridge (RM 278.49-270.64) 7.8 miles						
3,250	4.38	15.22	1.31	361	352	-
4,000	4.64	15.39	1.29	390	385	9%
5,000	4.78	15.60	1.32	481	466	32%
6,000	5.09	15.81	1.38	505	488	39%
Balls Ferry Bridge to Battle Creek (RM 270.64-268.6) 2.0 miles						
3,250	3.19	4.09	1.98	381	138	-
4,000	3.59	4.49	2.22	390	141	2%
5,000	4.06	4.97	2.47	402	146	5%
6,000	4.47	5.26	2.83	413	151	9%
Battle Creek to Jelly's Ferry (RM 268.6-261.5) 7.1 miles						
3,250	3.81	5.42	1.72	355	266	-
4,000	4.14	5.85	1.82	378	285	7%
5,000	4.49	6.38	1.96	405	305	15%
6,000	4.83	6.82	2.09	423	320	20%
Jelly's Ferry to Bend Bridge (RM 268.6-261.5) 9.3 miles						
3,250	5.75	11.45	1.95	246	257	-
4,000	6.00	11.60	2.12	262	276	7%
5,000	6.27	11.52	2.29	284	302	18%
6,000	6.51	11.85	2.48	305	326	27%
Bend Bridge to RBDD (RM 261.5-237.54) 14.7 miles						
3,250	5.19	13.65	1.88	367	694	-
4,000	5.57	14.05	2.12	381	717	3%
5,000	5.94	14.54	2.39	398	749	8%
6,000	6.28	15.01	3.02	415	781	13%

Notes:
1. Hydraulic depth is calculated by dividing the cross sectional flow area by the top width of the flow (see Figure 6). Average hydraulic depth is calculated by averaging the hydraulic depth at each cross section within the reach. Maximum and minimum values represent the maximum and minimum hydraulic depth calculated at individual cross sections within the reach. These values do not represent the maximum or minimum depth of flow, but provide an indication of the geometry of the channel within the reach.
2. Wetted area is estimated by multiplying the wetted perimeter (Figure 6) by the reach length (distance between cross sections) at each cross section. Total represents the sum of the wetted area calculated at each cross section within the reach.

TABLE III-6
POTENTIAL INCREASES IN AQUATIC HABITAT WITH 6.5-FOOT AND 18.5-FOOT DAM RAISE SCENARIOS

Reach	Reach Length (miles)	6.5-Foot Raise Flow Target: 3,575 cfs Estimated Increase in Aquatic Area (Acres)	18.5-Foot Raise Flow Target: 5,194 cfs Estimated Increase in Aquatic Area (Acres)
Keswick to ACID Dam	3.492	2.1	11.2
ACID Dam to HWY 44 Bridge	1.978	1.8	16.1
HWY44 Bridge to Airport Road Bridge	11.96	11.7	62.9
Airport Road Br to Balls Ferry Br	7.85	13.4	129.3
Balls Ferry Bridge to Battle Creek	2.04	1.3	8.0
Battle Creek to Jelly's Ferry	7.1	7.9	42.3
Jelly's Ferry to Bend Bridge	9.27	8.1	50.2
Bend Bridge to RBDD	14.69	10.3	62.0
Total	**52.91**	**56.6 acres**	**382.0 acres**

Note: Estimated increases in aquatic area are interpolated based on the target flow of the scenario and the flows simulated in the HEC-RAS analysis.

Equating the estimated increases in aquatic habitat to increases in anadromous fish survival is not possible at this time. This is largely because anadromous fish survival is dependent on numerous factors in addition to flow: water temperature, climatic variability, the number of fish migrating upstream, age of the returning fish, etc. Further, there are many different ways in which minimum flows could be revised, seasonally, to benefit anadromous fish. A study by the United States Geological Survey (USGS)(Modeling Chinook Salmon with SALMOD on the Sacramento River, California, December 2001) developed several findings useful to this analysis. This study used the SALMOD model to predict changes to anadromous fish survival under a variety of flow, temperature, and other habitat conditions. This study reported that it is unclear whether spawning habitat or rearing habitat is more limiting to anadromous fish survival; this is an important factor in identifying the most effective time of year to increase the minimum flow requirement (during spawning periods versus during rearing periods). Further, the study found no clear tie between the life-stage success of any particular run and a single habitat indicator (temperature, food availability, or habitat availability, for example). Model simulations indicated that any regime (flow) change will benefit the spring-run.

This analysis specifically addressed potential aquatic habitat changes resulting from increasing the existing 3,250 cfs requirement for the winter-run, but other seasonal flow changes could also be made to benefit the various life stages of salmon on the Sacramento River. Although detailed analyses of how potential changes in seasonal flows could benefit anadromous fish are beyond the scope of this initial study, the information summarized above and gathered by others can be useful in plan formulation.

Care must be taken in interpreting the results of the HEC-RAS analysis. As described previously, the HEC-RAS model was developed to simulate high magnitude flood flows, rather than the low flows simulated in this analysis. Consequently, the detail with which channel geometry is represented in the model varies significantly throughout. Further, the aquatic habitat figures are rough estimates based on the results at each cross section; the accuracy of these calculations is influenced by cross section spacing and the uniformity of the channel between the cross sections. Also, the hydraulic depth calculations are useful indicators of the character of the channel within the reach, but do not represent actual depths of flow within the cross sections. Last, the evaluation does not provide any indication of the quality or suitability of the habitat for spawning and rearing of anadromous fish. Still, the simulation results provide useful indications of the changes in aquatic habitat that could occur if minimum flow targets for releases from Keswick were increased.